Modeling of radiation transport in fluctuating edge plasmas: a statistical approach

J. Rosato, A. Mekkaoui, Y. Marandet, D. Reiter[a], V. Kotov[a], H. Capes, L. Godbert-Mouret, M. Koubiti, R. Stamm

PIIM, UMR 6633 Univ. Provence / CNRS, Centre de St. Jérôme, F-13397 Marseille Cedex 20, France
[a]IEF-4 Plasmaphysik, Forschungszentrum Jülich GmbH, Trilateral Euregio Cluster, Euratom Association, D-52425 Jülich, Germany
E-mail: joel.rosato@univ-provence.fr

The plasma at the edge of tokamaks can be very optically thick to the hydrogen resonance lines. This has been demonstrated for high-density divertor conditions, experimentally (from line ratio measurements [1]) and numerically using coupled radiation transport / atomic kinetic codes [2, 3]. A problem currently under investigation is the role of atomic line radiation transport on the ionization–recombination balance of the edge plasma. Estimates show that the photon mean free path l_{mfp} of the first hydrogen resonance lines is shorter than 10 cm at $N_{at} = 10^{13}$ cm^{-3} and $T_{at} = 10$ eV, i.e. in typical SOL conditions. This is even worse in high-density divertor conditions where N_{at} can reach values up to 10^{15} cm^{-3} and higher. Up to now, all of the numerical investigations done so far were made assuming a plasma background whose typical variation scales are much larger than the neutral and radiation transport scales. This approximation is questionable for tokamaks, where the turbulence radial correlation length l_{turb} (estimated as $10\rho_s$ [4]) can be of the same order as or even smaller than the photon mean free path ($l_{turb} \sim 1$ mm at $T_e = 10$ eV and $B = 5$ T). Various approaches have been proposed recently for an effective transport model for neutrals in the framework of EIRENE modeling [5, 6]. Concerning radiation transport, a preliminary attempt to retain fluctuations has been done by a statistical parameterization of the fluctuations in the rates appearing in the radiative transfer equation [7]. This parameterization relies on a quasilinear-type approximation which assumes small ratio l_{turb}/l_{mfp}. In this work, we propose a modification of the model suitable for arbitrary value of l_{turb}/l_{mfp}. The philosophy of the model is inspired from the "model microfield method" (MMM) used for Stark line shape modeling [8]. The plasma parameters (N_e, T_e etc.) appearing in the photon source and loss terms are described as stepwise constant stochastic processes which jump at randomly chosen positions according to a given probability density function. The MMM has been proposed recently for similar purpose in collisional-radiative modeling [9] and an application was done to impurity radiation in fluctuating tokamak edge plasmas [10]. Here, we adapt the formalism to radiation transport and calculate the spectral profile of the first resonance lines of hydrogen. Implementation of the model in the EIRENE code for self-consistent calculations of the radiation field and neutral gas will be also addressed.

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